

# ZOOM LENS AND OPTICAL APPARATUS USING THE SAME

## BACKGROUND OF THE INVENTION

5           The present invention relates to a zoom lens and optical apparatus using the same. In particular, the present invention is suitable for photograph cameras, video cameras, electronic still cameras, digital cameras, 3-CCD compatible electronic cameras and the like which attempt to obtain still images and stabilize shot images by displacing images by moving part of lens units that constitute the zoom lens so as to  
10   have a component of a direction perpendicular to an optical axis, and by optically correcting blurs in shot images when the zoom lens vibrates (or inclines).

          A so-called five-unit zoom lens including five lens units having, in order from the object side, positive, negative, positive, negative and positive refractive powers has conventionally been known as a zoom type suitable for a single-lens reflex camera.

15           This zoom type is suitable for a zoom lens of a high magnification range since each lens unit moves a relatively small distance, and advantageous in making wide-angle a short focus side since it may easily keep a long back focus.

          This type of zoom lens is disclosed in U.S. Patent Nos. 4,437,732, 4,498,741, Japanese Patent Publications No. Sho 61-51291 and the like. This assignee also  
20   discloses similar zoom lenses in Japanese Laid-Open Patent Applications Nos. Hei 6-230285, Hei 8-179213, Hei 9-304697 and the like.

          On the other hand, a shooting system blurs images when receiving occasional vibrations. Various zoom lenses each including a mechanism for compensating for blurred images caused by the occasional vibrations (*i.e.*, a vibration-resistant  
25   mechanism) have conventionally been proposed. For example, U.S. Patent Nos. 5,270,857, 6,124,972 and the like propose means for moving part of lens units which

constitute an optical system (of the zoom lens) in a direction approximately perpendicular to the optical axis so as to compensating for vibration caused blurred images.

5 U.S. Patent No. 5,270,857 discloses a zoom lens in its embodiment that is suitable primarily for a taking lens for use with a lens shutter camera, and teaches a structure that compensates for blurred images by moving in a direction approximately perpendicular to the optical axis partial lens unit part of a three-unit zoom lens that includes, in order from an object side, a first lens unit of negative refractive power, a  
10 second lens unit of positive refractive power, and a third lens unit of negative refractive power.

U.S. Patent No. 6,124,972 discloses a zoom lens in its embodiment that is suitable primarily for a standard zoom lens for use with a single-lens reflex camera, and teaches a structure that compensates for blurred images by moving in a direction  
15 approximately perpendicular to the optical axis a second lens unit in a four-unit zoom lens that includes, in order from an object side, a first lens unit of positive refractive power, the second lens unit of negative refractive power, a third lens unit of positive refractive power, and a fourth lens unit of negative refractive power.

In general, a mechanism for vibrating part of lens unit in a shooting system so  
20 as to eliminate blurs in a shot image and obtaining still images requires a larger image-blur correcting capability, to smaller shift and rotary amounts of lens unit(s) (or movable lens unit(s)) to be vibrated for blur correction, a wholly compact apparatus, and the like.

In addition, if the defocus of the movable lens unit causes much eccentric  
25 aberration, the eccentric aberration defocuses images after blurs are corrected.

Therefore, an optical system having the vibration resistant function requires a smaller amount of eccentric aberration generated when the movable lens is moved in a direction orthogonal to the optical axis and made in an eccentric state, a larger blur-image correction capability with a smaller shift amount of the movable lens unit, a large so-called eccentric sensitivity (that is a ratio  $\Delta X/\Delta H$  of a correction amount  $\Delta X$  to blurred images to a unit shift amount  $\Delta H$ ), and the like.

The zoom lens disclosed in U.S. Patent No. 5,270,857 is a zoom lens that is suitable primarily for a zoom lens for use with a lens shutter camera and equipped with a mechanism for compensating for vibrations. In attempting to apply the zoom lens structure disclosed herein to a single-lens reflex camera, the back focus to keep a drive space for a QR mirror (quick return mirror) often runs short.

The zoom lens disclosed in U.S. Patent No. 6,124,972 is a standard zoom lens for a single-lens reflex camera and equipped with a mechanism for compensating for vibrations, but such a four-unit structure of the lens unit makes it difficult to realize high range zooming.

## **SUMMARY OF THE INVENTION**

It is an exemplified object of the present invention to provide a zoom lens and optical apparatus using the same which have high range zooming and maintains good stability of optical performance throughout the zoom range, facilitating a compact size of the entire apparatus even when equipped with a (vibration resistant) mechanism for compensating for vibrations, and has a vibration resistant function which may provide good images during compensation for vibrations.

In order to achieve the above object, a zoom lens of one aspect of the present invention comprises, in order from an object side, a first lens unit of positive refractive

power, a second lens unit of negative refractive power, a third lens unit of positive refractive power, a fourth lens unit of negative refractive power, and a fifth lens unit of positive refractive power, wherein the zoom lens moves part of the lens units during zooming from a wide-angle end to a telephoto end so that a separation between the

5 first lens unit and the second lens unit increases, a separation between the second lens unit and the third lens unit decreases, a separation between the third lens unit and the fourth lens unit increases, and a separation between the fourth lens unit and the fifth lens unit decreases, and wherein an image is displaced by moving at least part of the fourth lens unit so as to have a component of a direction perpendicular to an optical

10 axis. According to the zoom lens, third lens constricts a luminous flux incident to the fourth lens unit. Therefore, it is relatively easy to miniaturize the fourth lens unit. In this zoom type, the fourth lens unit assists the zoom range in becoming enough large and serves to properly correct fluctuations in various aberrations during zooming, thus providing relatively small zooming contributions. Therefore, the present invention is

15 characterized in that it is easy to properly control a remaining aberration amount in this lens unit. Due to this characteristic, the fourth lens unit may appropriately correct various eccentric aberrations during defocusing. Thereby, the zoom lens of the present invention may make small the entire apparatus to which such a zoom lens is applied, and maintain good stability of optical performance during compensation for vibrations.

20 In the above zoom lens, the fourth lens unit comprises two or more lens components including a lens component of negative refractive power, and the image is displaced by moving the lens component of negative refractive power so as to have the component of the direction perpendicular to the optical axis. According to this zoom lens, the lens component of negative refractive power may be set independent of a

25 refractive power suitable for the compensation for vibrations by setting the refractive power of the entire fourth lens unit to be suitable for the zoom lens, and by assigning

the lens component of negative refractive power to an image displacement correction unit.

In the above zoom lens, the fourth lens unit includes a lens component of positive refractive power and a lens component of negative refractive power.

5 According to this zoom lens, the lens component of positive refractive power may easily make strong the lens component of negative refractive power as an image displacement correction unit, thereby making small the defocus amount during compensation for vibrations, and rendering compact the entire apparatus.

10 In the above zoom lens, a condition  $0.01 < f_1/f_4 < 0.8$  is satisfied where  $f_1$  is a focal length of the lens component of negative refractive power so as to have the component of the direction perpendicular to the optical axis, and  $f_4$  is a focal length of the fourth lens unit. This zoom lens may properly set a ratio of the focal length of the lens component of negative refractive power that is moved so as to have a component of the direction perpendicular to the optical axis, to that of the fourth lens unit. Under  
15 this condition, when this ratio exceeds the upper limit, the defocus amount becomes too large during compensation for vibrations. When this ratio exceeds the lower limit, on the other hand, it becomes difficult to correct various aberrations, in particular, the coma aberration at a telephoto end during compensation for vibrations.

20 In the above zoom lens, the fourth lens unit includes, in order from the object side, a lens component of positive refractive power, and a lens component of negative refractive power that displaces an image by moving the lens component of negative refractive power so as to have the component of the direction perpendicular to the optical axis. According to this zoom lens, the luminous-flux constricting power by the lens component of positive refractive power makes small a diameter of the luminous  
25 flux incident to the lens unit of negative refractive power, consequently enabling to make small the image displacement correction unit.

In the above zoom lens, a condition  $-0.8 < \beta_{rt} < -0.1$  is satisfied where  $\beta_{rt}$  is a lateral magnification at a telephoto end of an optical member disposed closer to the image plane side than the lens component of negative refractive power that is moved so as to have the component of the direction approximately perpendicular to the axial.

5 According to this zoom lens, when the lateral magnification exceeds the upper limit, the absolute value of the image displacement sensitivity in the image displacement correction unit tends to become small. As a result, the defocus amount becomes large during compensation for vibrations, and the size of the entire apparatus becomes large. Conversely, when the lateral magnification exceeds the lower limit, the absolute value of the image displacement sensitivity in the image displacement correction unit tends to large, but the displacement of the image displacement correction unit requires the high precise control mechanism and the entire apparatus becomes disadvantageously large.

10 In the above zoom lens, the lens component of positive refractive power comprises a cemented lens of a positive lens and a negative lens or a single positive lens, and the lens component of negative refractive power comprises a cemented lens of a positive lens and a negative lens.

15 Further, according to another aspect of the present invention, an optical apparatus comprising the above zoom lens. Since this optical apparatus includes the above zoom lens and achieves the same operation, the optical apparatus may have a compact body and good stability of optical performance.

20 Other objects and further features of the present invention will become readily apparent from the following description of preferred embodiments with reference to accompanying drawings.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a sectional view of a zoom lens of numerical example 1 among embodiments of the present invention.

5        FIG. 2 shows graphic representations of longitudinal aberrations at a wide-angle end of a reference state in the zoom lens of the numerical example 1 among the instant embodiments.

10       FIG. 3 shows graphic representations of longitudinal aberrations at a middle focal length of a reference state in the zoom lens of the numerical example 1 among the instant embodiments.

15       FIG. 4 shows graphic representations of longitudinal aberrations at a telephoto end of a reference state in the zoom lens of the numerical example 1 among the instant embodiments.

20       FIG. 5 shows graphic representations of lateral aberrations at a wide-angle end when the zoom lens of the numerical example 1 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of  $0.3^\circ$ .

25       FIG. 6 shows graphic representations of lateral aberrations at a middle focal length when the zoom lens of the numerical example 1 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of  $0.3^\circ$ .

30       FIG. 7 shows graphic representations of lateral aberrations at a telephoto end when the zoom lens of the numerical example 1 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of  $0.3^\circ$ .

FIG. 8 is a sectional view of a zoom lens of numerical example 2 among embodiments of the present invention.

FIG. 9 shows graphic representations of longitudinal aberrations at a wide-angle end of a reference state in the zoom lens of the numerical example 2 among the  
5 instant embodiments.

FIG. 10 shows graphic representations of longitudinal aberrations at a middle focal length of a reference state in the zoom lens of the numerical example 2 among the instant embodiments.

FIG. 11 shows graphic representations of longitudinal aberrations at a telephoto end of a reference state in the zoom lens of the numerical example 2 among the instant  
10 embodiments.

FIG. 12 shows graphic representations of lateral aberrations at a wide-angle end when the zoom lens of the numerical example 2 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of 0.3°.   
15

FIG. 13 shows graphic representations of lateral aberrations at a middle focal length when the zoom lens of the numerical example 2 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of 0.3°.

FIG. 14 shows graphic representations of lateral aberrations at a telephoto end when the zoom lens of the numerical example 2 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of 0.3°.   
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FIG. 15 is a sectional view of a zoom lens of numerical example 3 among  
25 embodiments of the present invention.



FIG. 16 shows graphic representations of longitudinal aberrations at a wide-angle end of a reference state in the zoom lens of the numerical example 3 among the instant embodiments.

FIG. 17 shows graphic representations of longitudinal aberrations at a middle focal length of a reference state in the zoom lens of the numerical example 3 among the instant embodiments.

FIG. 18 shows graphic representations of longitudinal aberrations at a telephoto end of a reference state in the zoom lens of the numerical example 3 among the instant embodiments.

FIG. 19 shows graphic representations of lateral aberrations at a wide-angle end when the zoom lens of the numerical example 3 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of  $0.3^\circ$ .

FIG. 20 shows graphic representations of lateral aberrations at a middle focal length when the zoom lens of the numerical example 3 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of  $0.3^\circ$ .

FIG. 21 shows graphic representations of lateral aberrations at a telephoto end when the zoom lens of the numerical example 3 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of  $0.3^\circ$ .

FIG. 22 is a sectional view of a zoom lens of numerical example 4 among embodiments of the present invention.

FIG. 23 shows graphic representations of longitudinal aberrations at a wide-angle end of a reference state in the zoom lens of the numerical example 4 among the instant embodiments.

FIG. 24 shows graphic representations of longitudinal aberrations at a middle focal length of a reference state in the zoom lens of the numerical example 4 among the instant embodiments.

FIG. 25 shows graphic representations of longitudinal aberrations at a telephoto end of a reference state in the zoom lens of the numerical example 4 among the instant embodiments.

FIG. 26 shows graphic representations of lateral aberrations at a wide-angle end when the zoom lens of the numerical example 4 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of  $0.3^\circ$ .

FIG. 27 shows graphic representations of lateral aberrations at a middle focal length when the zoom lens of the numerical example 4 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of  $0.3^\circ$ .

FIG. 28 shows graphic representations of lateral aberrations at a telephoto end when the zoom lens of the numerical example 4 among the instant embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of  $0.3^\circ$ .

FIG. 29 is a schematic diagram of an essential part of the optical apparatus using the zoom lens of the present invention.

#### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

A description will now be given of the zoom lenses the embodiments of the present invention with reference to drawings.

FIG. 1 is a sectional view of a zoom lens of numerical example 1 among  
embodiments of the present invention. FIG. 2 shows graphic representations of  
longitudinal aberrations at a wide-angle end of a reference state in the zoom lens of  
the numerical example 1 among the instant embodiments. FIG. 3 shows graphic  
5 representations of longitudinal aberrations at a middle focal length of a reference state  
in the zoom lens of the numerical example 1 among the instant embodiments. FIG. 4  
shows graphic representations of longitudinal aberrations at a telephoto end of a  
reference state in the zoom lens of the numerical example 1 among the instant  
embodiments. FIG. 5 shows graphic representations of lateral aberrations at a wide-  
10 angle end when the zoom lens of the numerical example 1 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
angle of view of  $0.3^\circ$ . FIG. 6 shows graphic representations of lateral aberrations at a  
middle focal length when the zoom lens of the numerical example 1 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
15 angle of view of  $0.3^\circ$ . FIG. 7 shows graphic representations of lateral aberrations at a  
telephoto end when the zoom lens of the numerical example 1 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
angle of view of  $0.3^\circ$ .

FIG. 8 is a sectional view of a zoom lens of numerical example 2 among  
20 embodiments of the present invention. FIG. 9 shows graphic representations of  
longitudinal aberrations at a wide-angle end of a reference state in the zoom lens of  
the numerical example 2 among the instant embodiments. FIG. 10 shows graphic  
representations of longitudinal aberrations at a middle focal length of a reference state  
in the zoom lens of the numerical example 2 among the instant embodiments. FIG. 11  
25 shows graphic representations of longitudinal aberrations at a telephoto end of a  
reference state in the zoom lens of the numerical example 2 among the instant

embodiments. FIG. 12 shows graphic representations of lateral aberrations at a wide-angle end when the zoom lens of the numerical example 2 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
angle of view of  $0.3^\circ$ . FIG. 13 shows graphic representations of lateral aberrations at a  
middle focal length when the zoom lens of the numerical example 2 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
angle of view of  $0.3^\circ$ . FIG. 14 shows graphic representations of lateral aberrations at a  
telephoto end when the zoom lens of the numerical example 2 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
angle of view of  $0.3^\circ$ .

FIG. 15 is a sectional view of a zoom lens of numerical example 3 among  
embodiments of the present invention. FIG. 16 shows graphic representations of  
longitudinal aberrations at a wide-angle end of a reference state in the zoom lens of  
the numerical example 3 among the instant embodiments. FIG. 17 shows graphic  
representations of longitudinal aberrations at a middle focal length of a reference state  
in the zoom lens of the numerical example 3 among the instant embodiments. FIG. 18  
shows graphic representations of longitudinal aberrations at a telephoto end of a  
reference state in the zoom lens of the numerical example 3 among the instant  
embodiments. FIG. 19 shows graphic representations of lateral aberrations at a wide-  
angle end when the zoom lens of the numerical example 3 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
angle of view of  $0.3^\circ$ . FIG. 20 shows graphic representations of lateral aberrations at a  
middle focal length when the zoom lens of the numerical example 3 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
angle of view of  $0.3^\circ$ . FIG. 21 shows graphic representations of lateral aberrations at a  
telephoto end when the zoom lens of the numerical example 3 among the instant

embodiments corrects blurred images at an infinite distant object corresponding to an angle of view of  $0.3^\circ$ .

FIG. 22 is a sectional view of a zoom lens of numerical example 4 among  
embodiments of the present invention. FIG. 23 shows graphic representations of  
5 longitudinal aberrations at a wide-angle end of a reference state in the zoom lens of  
the numerical example 4 among the instant embodiments. FIG. 24 shows graphic  
representations of longitudinal aberrations at a middle focal length of a reference state  
in the zoom lens of the numerical example 4 among the instant embodiments. FIG. 25  
shows graphic representations of longitudinal aberrations at a telephoto end of a  
10 reference state in the zoom lens of the numerical example 4 among the instant  
embodiments. FIG. 26 shows graphic representations of lateral aberrations at a wide-  
angle end when the zoom lens of the numerical example 4 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
angle of view of  $0.3^\circ$ . FIG. 27 shows graphic representations of lateral aberrations at a  
15 middle focal length when the zoom lens of the numerical example 4 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
angle of view of  $0.3^\circ$ . FIG. 28 shows graphic representations of lateral aberrations at a  
telephoto end when the zoom lens of the numerical example 4 among the instant  
embodiments corrects blurred images at an infinite distant object corresponding to an  
20 angle of view of  $0.3^\circ$ .

In the sectional view of lenses shown in FIG. 1, (W) denotes a wide-angle end,  
(M) denotes a midpoint, and (T) denotes a telephoto end of a zoom position.

In each numerical example,  $Y$  is a height of an image,  $f$  is a focal length,  $f_{NO}$  is  
an F number.

25 In sectional views of lenses shown in FIGs. 1, 8, 15, and 22, L1 is a first unit of  
positive refractive power (*i.e.*, first lens unit), L2 is a second unit of negative

refractive power (*i.e.*, second lens unit), L3 is a third unit of positive refractive power (*i.e.*, third lens unit), L4 is a fourth unit of negative refractive power (*i.e.*, fourth lens unit), L5 is a fifth unit of positive refractive power (*i.e.*, fifth lens unit). SP is a stop and provided at an object side of the third unit. IP is an image plane at which a silver-halide film and a photoelectric conversion element in a CCD, CMOS etc. are located.

The fourth unit L4 denotes a lens component L4a of positive refractive power and a lens component L4b of negative refractive power.

In this embodiment, during zooming from the wide-angle end to the telephoto end, as shown in FIG. 1, each lens unit is moved so that a separation between the first and second units increases, a separation between the second and third units decreases, a separation between the third and fourth units increases, and a separation between the fourth and fifth units decreases. The Stop SP moves integrally with the third unit. The third unit moves integrally with the fifth unit.

Thus, the instant embodiment specifies the refractive power for each lens unit and moves each lens unit during zooming. Thereby, the instant embodiment realizes the high range zooming with effective zoom shares among respective lens units, and properly corrects aberrations throughout the entire zoom range. The normal focus from the infinite distant object to a closest object moves a compact and light second unit L2 to the object side.

Other lens units except the second unit may conduct focusing.

The instant embodiment moves the lens component L4b of negative refractive power as part of the fourth unit in a direction perpendicular to the optical axis, displacing an image, and correcting blurred image caused when the zoom lens vibrates. An image is displaced when the lens component L4b is moved so as to have a component perpendicular to the optical axis, and thus the moving direction is not necessarily limited to the perpendicular direction.

Blurred images can be promptly corrected by using the compact and light lens component L4b of negative refractive power for a vibration resistant member among the fourth unit, and the image quality is properly maintained by keeping small the fluctuations among aberrations in preventing vibrations.

5 Since the zoom lens of the present invention comprises, in order from the object side, the first, second, third, fourth and fifth having positive, negative, positive, negative, positive refractive powers respectively, the third lens unit constricts the luminous flux incident to the fourth lens unit. Therefore, it is relatively easy to miniaturize the fourth lens unit. In this zoom type, the fourth lens unit assists the  
10 zooming range in becoming enough large and serves to properly correct fluctuations among various aberrations during zooming, thus providing relatively small contributions to zooming. Thus, the present invention is characterized in that it is easy to properly control the remaining aberration amount in this lens unit. Due to this characteristic, the fourth lens unit may appropriately correct various eccentric  
15 aberrations during defocusing.

From the above two reasons, the present invention assigns the fourth lens unit of negative refractive power to an image displacement correction unit (*i.e.*, vibration-resistant lens unit) in the aforementioned zoom type, rendering the entire apparatus compact and maintaining good stability of optical performance during compensation  
20 for vibrations.

While the zoom lens of the present invention may achieve a given object by the above structure, it is preferable to satisfy at least one of following structures to obtain better optical performance.

(a-1) One way is to displace an image and correct a blurred image by  
25 including two or more lens components including a lens component of negative refractive power in the fourth lens unit and by moving the lens component of negative

refractive power so as to have a component in the direction perpendicular to the optical axis.

In the zoom lens, it is preferable to set the refractive power arrangement for each unit suitable for zooming and aberration corrections, so as to obtain good stability of optical performance. In addition to the above, a refractive power of the image displacement correction unit (*i.e.*, a vibration resistant lens unit) is preferably made suitable for compensation for vibrations in the vibration-compensating zoom lens.

Accordingly, the lens component of negative refractive power is easily and independently set to the refractive power suitable for compensation for vibrations by including in the fourth lens unit two or more lens components including a lens component of negative refractive power, and by assigning the refractive power of the entire fourth lens unit to that suitable for a zoom lens.

(a-2) Another way is to include the lens component of positive refractive power and the lens component of negative refractive power in the fourth lens unit.

When the fourth lens unit of negative refractive power comprises a lens component of positive refractive power and a lens component of negative refractive power, it becomes easy to enhance the refractive power of the lens component of negative refractive power as the image displacement correction unit, to make small the defocus amount during compensation for vibrations, and thus to render compact the entire apparatus.

(a-3) Still another way is to satisfy a condition  $0.01 < f_{is}/f_4 < 0.8$  --- (1) where  $f_{is}$  is a focal length of the lens component of negative refractive power that is moved so as to have the component of the direction perpendicular to the optical axis, and  $f_4$  is a focal length of the fourth lens unit.



This equation (1) is a condition to properly set up a ratio of the focal length of the lens component of negative refractive power that is moved so as to have a component of the direction perpendicular to the optical axis, to that of the fourth lens unit. When it exceeds the upper limit, the defocus amount becomes too large during compensation for vibrations, and when it exceeds the lower limit, it becomes difficult to correct various aberrations, in particular the coma aberration at a telephoto end during compensation for vibrations.

More preferably, the equation (1) is set into the following numerical range:

$$0.15 < f_{is}/f_4 < 0.45 \quad \text{--- (1a)}$$

(a-4) Another way is to include, in order from the object side, a lens component of positive refractive power and a lens component of negative refractive power in the fourth lens unit, and to displace an image by moving the lens component of negative refractive power in the direction approximately perpendicular to the optical axis, correcting image blurs.

By including, in order from the object side, a lens component of positive refractive power and a lens component of negative refractive power in the fourth lens unit, and displacing an image position by moving the lens component of negative refractive power in the direction approximately perpendicular to the optical axis, correcting blurs in image, the luminous-flux constricting power by the lens component of positive refractive power makes small a diameter of the luminous flux incident to the lens unit of negative refractive power, consequently enabling to make small the image displacement correction unit.

(a-5) Another way is to satisfy a condition  $-0.8 < \beta_{rt} < -0.1$  --- (2) where  $\beta_{rt}$  is a lateral magnification at a telephoto end of an optical member disposed closer to the image plane side than the lens component of negative refractive power that is to be

moved so as to have the component in the direction approximately perpendicular to the axial.

The image displacement sensitivity of the image displacement correction unit (*i.e.*, vibration resistant lens unit) is represented by the following equation:

$$ES = (1 - \beta_{is}) \times Br \quad \text{--- (3)}$$

where ES is the image displacement sensitivity (*i.e.*, image displacement amount per unit displacement amount of the image displacement correction unit),  $\beta_{is}$  is a magnification of the image displacement correction unit, Br is a magnification of an optical system disposed between the image displacement correction unit and the image plane.

According to the equation (3), it may be said that the magnification of the optical system disposed between the image displacement correction unit and the image plane is proportional to the image displacement sensitivity.

It is a condition set by taking the equation (2) into account, and when it exceeds the upper limit, an absolute value of the image displacement sensitivity in the image displacement correction unit tends to be small, and consequently the entire apparatus tends to be large since the defocus amount increases during compensation for vibrations. On the contrary, when it exceeds the lower limit, the absolute value of the image displacement sensitivity tends to be large, but the displacement of the image displacement correction unit requires high precise control mechanism and disadvantageously making the entire apparatus larger.

It is preferable to set the equation (2) into the following numerical range:

$$-0.5 < \beta_{rt} < -0.2 \quad \text{--- (2a)}$$

As discussed, according to the instant embodiment, the zoom range becomes high at the wide-angle end such that the angle of view becomes about 74° that is four times large, while the good stability of optical performance is maintained throughout

the zoom range. In addition, even when it is equipped with a (vibration resistant) mechanism for compensating vibrations, the entire apparatus may become small and the zoom lens may provide a good image during compensation for vibrations.

Next follows a description of a single-lens reflex camera using a zoom lens  
5 having a vibration resistant function of an embodiment according to the present invention, with reference to FIG. 29.

In FIG. 29, 10 denotes a camera body, 11 denotes a zoom lens of the present invention, and 12 denotes photographing means, which includes a film, CCD as a photoelectric conversion element, etc. 13 denotes a finder system including a focus plate 15 on which a subject image is formed, a pentaprism 16 as an image inverting means, and an eyepiece 17 for observing the subject image on the focus plate 15. 14 denotes a quick return mirror.

Thus, an application of the inventive zoom lens to an optical apparatus such as a single-lens reflex camera would render small the optical apparatus and enhance the optical performance.

Next follows numerical examples of the present invention. In these numerical examples, "i" denotes an order of an optical surface from the object side, and  $R_i$  represents a radius of curvature of the i-th optical surface (i-th surface).  $D_i$  is a separation between the i-th and i+1-th surfaces,  $N_i$  and  $v_i$  are the refractive power and  
20 abbe number of the material of the i-th optical member for d-line.

Table 1 shows a relationship between the above equations and various numerical values in the numerical examples.

The aspheric shape is expressed by the following equation:

$$X = \frac{(1/R)H^2}{1 + \sqrt{1 - (H/R)^2}} + AH^2 + BH^4 + CH^6 + DH^8 + EH^{10}$$

where R is the radius of curvature at the center part of the lens surface, X is a displacement in the optical axis direction, H, A, B, C, D, E are aspheric coefficients, and "e-a" means " $\times 10^{-a}$ ".

### Numerical Example 1

$$f = 29.00 \sim 101.44 \quad F \# = 4.16 \sim 5.26 \quad 2\omega = 73.5 \sim 24.1$$

R 1 = 108.591	D 1 = 1.50	N 1 = 1.846660	$\nu$ 1 = 23.8
R 2 = 54.430	D 2 = 7.79	N 2 = 1.622992	$\nu$ 2 = 58.2
R 3 = 1851.906	D 3 = 0.20		
R 4 = 41.822	D 4 = 6.07	N 3 = 1.712995	$\nu$ 3 = 53.9
R 5 = 115.785	D 5 = Variable		
R 6 = 92.731	D 6 = 1.20	N 4 = 1.834000	$\nu$ 4 = 37.2
R 7 = 12.487	D 7 = 4.75		
R 8 = -35.612	D 8 = 1.10	N 5 = 1.804000	$\nu$ 5 = 46.6
R 9 = 33.983	D 9 = 0.20		
R10 = 24.005	D10 = 4.55	N 6 = 1.846660	$\nu$ 6 = 23.8
R11 = -41.539	D11 = 0.50		
R12 = -24.641	D12 = 1.00	N 7 = 1.772499	$\nu$ 7 = 49.6
R13 = -67.354	D13 = Variable		
R14 = Stop	D14 = 0.39		
R15 = 27.872	D15 = 1.00	N 8 = 1.846660	$\nu$ 8 = 23.8
R16 = 14.768	D16 = 5.30	N 9 = 1.603112	$\nu$ 9 = 60.6
R17 = -35.206	D17 = Variable		
R18 = -22.069	D18 = 3.27	N10 = 1.517417	$\nu$ 10 = 52.4
R19 = -24.545	D19 = 1.00	N11 = 1.834807	$\nu$ 11 = 42.7
R20 = 4016.395	D20 = 1.80		
R21 = -62.727	D21 = 2.82	N12 = 1.846660	$\nu$ 12 = 23.8
R22 = -14.382	D22 = 1.00	N13 = 1.723420	$\nu$ 13 = 38.0
R23 = 44.669	D23 = Variable		
R24 = -6743.672	D24 = 3.83	N14 = 1.583126	$\nu$ 14 = 59.4
* R25 = -26.332	D25 = 0.15		
R26 = 60.361	D26 = 5.25	N15 = 1.517417	$\nu$ 15 = 52.4
R27 = -25.811	D27 = 1.72		
R28 = -19.913	D28 = 1.40	N16 = 1.805181	$\nu$ 16 = 25.4
R29 = -134.908			

Variable \ Focal Length	29.00	48.73	101.44
Separation			
D 5	2.28	12.25	28.44
D13	13.91	7.96	1.34
D17	0.80	4.16	6.49
D23	9.13	5.77	3.43

### Aspheric Coefficients

25th Surface : A=0.00000e+00 B=1.45326e-06 C=-1.66852e-08 D=2.67704e-10 E=-1.39088e-12

## Numerical Example 2

$f = 29.01 \sim 101.49$   $Fno = 4.16 \sim 5.26$   $2\omega = 73.4 \sim 24.1$

R 1 = 110.043	D 1 = 1.50	N 1 = 1.846660	$\nu$ 1 = 23.8
R 2 = 54.731	D 2 = 7.80	N 2 = 1.622992	$\nu$ 2 = 58.2
R 3 = 1810.046	D 3 = 0.20		
R 4 = 39.913	D 4 = 6.02	N 3 = 1.712995	$\nu$ 3 = 53.9
R 5 = 110.448	D 5 = Variable		
R 6 = 86.720	D 6 = 1.20	N 4 = 1.834000	$\nu$ 4 = 37.2
R 7 = 12.155	D 7 = 4.61		
R 8 = -36.200	D 8 = 1.10	N 5 = 1.804000	$\nu$ 5 = 46.6
R 9 = 34.257	D 9 = 0.24		
R10 = 23.588	D10 = 4.67	N 6 = 1.846660	$\nu$ 6 = 23.8
R11 = -42.164	D11 = 0.50		
R12 = -24.466	D12 = 1.00	N 7 = 1.772499	$\nu$ 7 = 49.6
R13 = -74.405	D13 = Variable		
R14 = Stop	D14 = 0.39		
R15 = 27.660	D15 = 1.00	N 8 = 1.846660	$\nu$ 8 = 23.8
R16 = 14.694	D16 = 3.45	N 9 = 1.603112	$\nu$ 9 = 60.6
R17 = -37.267	D17 = Variable		
R18 = 22.808	D18 = 3.13	N10 = 1.517417	$\nu$ 10 = 52.4
R19 = -24.447	D19 = 1.00	N11 = 1.834807	$\nu$ 11 = 42.7
R20 = -1020.201	D20 = 1.81		
R21 = -58.858	D21 = 2.62	N12 = 1.846660	$\nu$ 12 = 23.8
R22 = -14.414	D22 = 1.00	N13 = 1.723420	$\nu$ 13 = 38.0
R23 = 49.840	D23 = Variable		
R24 = 1498.357	D24 = 3.72	N14 = 1.583126	$\nu$ 14 = 59.4
* R25 = -27.410	D25 = 0.16		
R26 = 57.947	D26 = 5.67	N15 = 1.517417	$\nu$ 15 = 52.4
R27 = -23.520	D27 = 1.73		
R28 = -19.690	D28 = 1.40	N16 = 1.805181	$\nu$ 16 = 25.4
R29 = -142.394			

Variable \ Focal Length	29.01	48.50	101.49
Separation \			
D 5	2.22	11.42	27.42
D13	13.30	7.55	1.07
D17	2.42	5.69	7.58
D23	8.38	5.11	3.22

### Aspheric Coefficients

25th Surface : A=0.00000e+00 B=4.07453e-06 C=-3.51279e-09 D=2.17623e-10 E=-1.03456e-12

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# Numerical Example 3

$f = 28.93 \sim 101.46$   $Fno = 4.16 \sim 5.42$   $2\omega = 73.6 \sim 24.1$

R 1 = 149.986	D 1 = 1.50	N 1 = 1.846660	$\nu$ 1 = 23.8
R 2 = 62.807	D 2 = 6.75	N 2 = 1.622992	$\nu$ 2 = 58.2
R 3 = -687.901	D 3 = 0.20		
R 4 = 40.254	D 4 = 5.38	N 3 = 1.712995	$\nu$ 3 = 53.9
R 5 = 113.210	D 5 = Variable		
R 6 = 120.661	D 6 = 1.20	N 4 = 1.834000	$\nu$ 4 = 37.2
R 7 = 13.182	D 7 = 4.93		
R 8 = -60.749	D 8 = 1.10	N 5 = 1.804000	$\nu$ 5 = 46.6
R 9 = 48.307	D 9 = 0.16		
R10 = 23.298	D10 = 3.35	N 6 = 1.846660	$\nu$ 6 = 23.8
R11 = -63.551	D11 = 1.03		
R12 = -37.174	D12 = 1.00	N 7 = 1.772499	$\nu$ 7 = 49.6
R13 = 136.041	D13 = Variable		
R14 = Stop	D14 = 0.39		
R15 = 26.220	D15 = 1.00	N 8 = 1.846660	$\nu$ 8 = 23.8
R16 = 13.480	D16 = 4.09	N 9 = 1.603112	$\nu$ 9 = 60.6
R17 = -49.033	D17 = Variable		
R18 = 26.427	D18 = 2.80	N10 = 1.749497	$\nu$ 10 = 35.3
R19 = 50.820	D19 = 2.34		
R20 = -45.974	D20 = 2.47	N11 = 1.805181	$\nu$ 11 = 25.4
R21 = -13.593	D21 = 1.00	N12 = 1.720000	$\nu$ 12 = 42.0
R22 = 80.110	D22 = Variable		
R23 = 138.377	D23 = 4.00	N13 = 1.583126	$\nu$ 13 = 59.4
* R24 = -31.298	D24 = 0.15		
R25 = 79.528	D25 = 6.59	N14 = 1.518229	$\nu$ 14 = 58.9
R26 = -19.312	D26 = 0.97		
R27 = -18.204	D27 = 1.40	N15 = 1.805181	$\nu$ 15 = 25.4
R28 = -132.609			

Variable \ Focal Length	28.93	49.59	101.46
Separation \			
D 5	2.43	9.76	27.02
D13	15.10	7.50	0.86
D17	0.92	4.41	6.42
D22	9.23	5.74	3.73

## Aspheric Coefficients

24th Surface: A=0.00000e+00 B=7.03758e-06 C=6.37933e-09 D=7.45372e-11 E=3.19869e-13

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# Numerical Example 4

$$f = 28.93 \sim 101.47 \quad Fno = 4.16 \sim 5.39 \quad 2\omega = 73.6 \sim 24.1$$

R 1 = 158.101	D 1 = 1.50	N 1 = 1.846660	$\nu$ 1 = 23.8
R 2 = 64.957	D 2 = 6.85	N 2 = 1.622992	$\nu$ 2 = 58.2
R 3 = -475.558	D 3 = 0.20		
R 4 = 39.273	D 4 = 5.36	N 3 = 1.712995	$\nu$ 3 = 53.9
R 5 = 103.251	D 5 = Variable		
R 6 = 82.467	D 6 = 1.20	N 4 = 1.834000	$\nu$ 4 = 37.2
R 7 = 13.021	D 7 = 4.71		
R 8 = -49.608	D 8 = 1.10	N 5 = 1.804000	$\nu$ 5 = 46.6
R 9 = 48.465	D 9 = 0.19		
R10 = 23.685	D10 = 3.23	N 6 = 1.846660	$\nu$ 6 = 23.8
R11 = -51.132	D11 = 0.46		
R12 = -29.985	D12 = 1.00	N 7 = 1.772499	$\nu$ 7 = 49.6
R13 = 169.279	D13 = Variable		
R14 = Stop	D14 = 0.39		
R15 = 27.398	D15 = 1.00	N 8 = 1.846660	$\nu$ 8 = 23.8
R16 = 14.452	D16 = 4.17	N 9 = 1.603112	$\nu$ 9 = 60.6
R17 = -205.716	D17 = 0.15		
R18 = 49.888	D18 = 2.00	N10 = 1.603112	$\nu$ 10 = 60.6
R19 = -472.421	D19 = Variable		
R20 = 30.321	D20 = 1.66	N11 = 1.749497	$\nu$ 11 = 35.3
R21 = 71.212	D21 = 1.81		
R22 = -54.125	D22 = 2.57	N12 = 1.805181	$\nu$ 12 = 25.4
R23 = -13.933	D23 = 1.00	N13 = 1.723420	$\nu$ 13 = 38.0
R24 = 57.841	D24 = Variable		
R25 = 182.745	D25 = 4.00	N14 = 1.583126	$\nu$ 14 = 59.4
* R26 = -37.682	D26 = 0.15		
R27 = 74.586	D27 = 6.45	N15 = 1.518229	$\nu$ 15 = 58.9
R28 = -19.824	D28 = 1.26		
R29 = -18.922	D29 = 1.40	N16 = 1.805181	$\nu$ 16 = 25.4
R30 = -107.252			

Variable \ Focal Length	28.93	49.39	101.47
Separation			
D 5	2.33	9.44	26.94
D13	14.86	7.81	1.61
D19	0.81	5.22	7.85
D24	9.00	4.59	1.96

## Aspheric Coefficients

26th Surface : A=0.00000e+00 B=1.10031e-05 C=1.14575e-08 D=2.70859e-10 E=-7.37022e-13

Table 1

Equations	Numerical Example 1	Numerical Example 2	Numerical Example 3	Numerical Example 4
fis/f4	0.398	0.378	0.214	0.274
$\beta_{rt}$	-0.265	-0.357	-0.273	-0.370

5

Thus, the instant embodiment may provide a zoom lens and optical apparatus using the same which have a high range zoom and maintains the good stability of

optical performance throughout the zoom range, facilitating a compact size of the entire apparatus even when including a (vibration resistant) mechanism for compensating vibrations, and may provide good images during compensation of vibrations.

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